

HIGH-QUALITY POWER RAMPING IN A COMMUNICATIONS TRANSMITTER

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to power ramping in a communications transmitter.

2. State of the Art

High quality RF (radio frequency) signals must ramp quickly from a condition of minimal output power to a condition of information-bearing modulation at a specified output power and back down to the condition of minimal output power. Such power ramping capability, illustrated in Figure 1, is required for transmitters in many time division multiple access (TDMA) communication systems. Example systems include those specified by the GSM and ANSI-136 standards, and combinations of the same (so-called multi-mode systems).

A fundamental requirement of these transmitters is that the acts of ramping up and ramping down must not violate specified limits on peak power in spectral bands away from the assigned RF channel (e.g., bands that would be allocated to other transmitters); the associated measurement is called the transient spectrum in some systems or the transient adjacent channel power (transient ACP) in others.

Present power ramping techniques must be tailored for each modulation type, and typically require unit-by-unit calibration (at least in the case of typical GMSK transmitters and conventional multi-mode transmitters). Even so, transient ACP performance is usually very sub-optimal.

The present invention is applicable to both conventional (I/Q) and polar modulation architectures. Polar modulation architectures, and similar architectures in which separate amplitude and phase paths are provided, are described, for example, in U.S. Patents 6,191,653, 6,194,963, 6,078,628, 5,705,959, 6,101,224, 5,847,602, 6,043,707, and 3,900,823, as well as French patent publication FR 2768574, all of which are incorporated herein by reference.

SUMMARY OF THE INVENTION

The present invention, generally speaking, provides for control of a modulator, such as a polar modulator or conventional linear modulator, to produce high quality RF signals that ramp quickly from a condition of minimal output power to a condition of information-bearing modulation at a specified output power and back down to the condition of minimal output power. Using a polar modulator, for example, it is theoretically possible to perform ramping without degrading the transient measurements beyond the degradation caused by the information-bearing modulation itself. This ideal can be closely approached in practice. Such ramping can be achieved without the need for extensive unit-by-unit calibration on the manufacturing line.

BRIEF DESCRIPTION OF THE DRAWING

The present invention may be further understood from the following description in conjunction with the appended drawing. In the drawing:

Figure 1 is a diagram illustrating power ramping in a communication system;

Figure 2 is a diagram illustrating operation of a conventional QAM modulator using a pulse shaping filter having an impulse response given by $p(t)$;

Figure 3 is a diagram of one example of $p(t)$;

Figure 4 is a diagram illustrating operation of a QAM modulator using prepended and appended zero-valued symbols to control ramping;

Figure 5 is a timing diagram of timing signal used in with the circuitry of Figure 6;

Figure 6 is a diagram of a portion of a transmitter including ramp control circuitry in accordance with an exemplary embodiment of the invention;

Figure 7 is a signal plot of results obtained using the ramp control circuit of Figure 6;

Figure 8 is a diagram of a pulse shaping filter function $p(t)$ used in the example of Figure 7;

Figure 9 is an exploded view of the rising edge of the ramp of a signal plot like that of Figure 7;

Figure 10 shows the rising edge of the ramp of Figure 9 when viewed on a logarithmic (dB) scale;

Figure 11 is similar to Figure 9 but shows the falling edge of the ramp;

Figure 12 is a block diagram illustrating application of the present ramping technique in a polar modulation architecture;

Figure 13 is a diagram of a pulse shaping filter function $n(t)$ used for D-AMPS;

Figure 14 is a diagram of a portion of a communications transmitter implementing ramping for D-AMPS;

Figure 15 is a block diagram illustrating GMSK ramping in a polar modulation architecture;

Figure 16 is a block diagram illustrating GMSK ramping in an I/Q architecture;

Figure 17 is a diagram illustrating the output $r(t)$ of the ramp generator in Figure 15 and Figure 16;

Figure 18 is a block diagram of a multi-mode transmitter in accordance with the present invention; and

Figure 19 is a timing diagram illustrating operation of the transmitter of Figure 18.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

For nearly all systems of interest, the complex envelope $x(t)$ of an information-bearing modulation can be expressed by the well-known equation

$$x(t) = \sum_n a_n p(t - nT)$$

which is equivalent to

$$x(nT + \tau) = \sum_{k=0}^L a_{n-k} p(kT + \tau)$$

where a_n is the n -th complex-valued symbol (typically drawn from a discrete constellation), $p(t)$ is the impulse response at time t of a pulse-shaping filter, and T is the symbol period. Time t can be either continuous or discrete. Operation of a conventional QAM modulator using a pulse shaping filter having an impulse response given by $p(t)$ is illustrated in Figure 2. Due to the desire to maintain spectral efficiency, $p(t)$ is typically a smooth pulse-like function as shown for example in Figure 3.

An important observation, previously unknown either with respect to polar modulators or conventional modulators, is exploited in accordance with the present invention to achieve ramping having the advantageous characteristics previously mentioned. It is that by prepending and appending a few zero-valued symbols to the finite-length sequence of information symbols belonging to a burst, the resulting complex envelope $x(t)$ naturally ramps up and down precisely as required. Furthermore, it can be shown mathematically that the transient spectral properties of $x(t)$ during these ramps are no worse than during the information-bearing modulation. A diagram illustrating operation of a QAM modulator using prepended and appended zero-valued symbols to control ramping is shown in Figure 4.

Figure 6 shows a portion of a transmitter including ramp control circuitry

in accordance with an exemplary embodiment of the invention. Prior to describing the circuitry of Figure 6, it will be useful to understand the relationship of certain timing signals used in the circuitry of Figure 6. These timing signals are shown in Figure 5. A sample clock signal is divided by some number T to obtain a symbol clock. A τ counter counts the sample clock pulse within one period of the symbol clock. In the example of Figure 5, $T = 4$.

Referring now to Figure 6, a pulse shaping filter 601 having impulse response coefficients $p(0), p(1), \dots, p((L+1)T-1)$ receives from a tapped delay line or shift register a group of symbols $a_n, a_{n-1}, a_{n-2}, \dots, a_{n-L}$. (For purpose of the present description, a shift-register implementation will be assumed.) As τ cycles through $0, 1, 2, \dots, T-1$, the indices $\tau, \tau+T, \tau+2T, \dots, \tau+LT$ select a subset of the impulse response coefficients for application within the circuit at a particular time. The subsets of impulse response coefficients applied at a particular time may be described as follows: at $\tau = 0$, the subset is $\{0, 1, \dots, T-1\}$; at $\tau = 1$, the subset is $\{T, T+1, \dots, 2T-1\}$; at $\tau = 2$, the subset is $\{2T, 2T+1, \dots, 3T-1\}$, and so forth, until at $\tau = T-1$, the subset is $\{T-1, T-1+T, T-1+2T, \dots, T-1+LT\}$. Hence, as τ cycles through $0, 1, 2, \dots, T-1$, the entire range of impulse response coefficients $p(0), p(1), \dots, p((L+1)T-1)$ will have been applied.

The pulse filter forms an output signal 603 given by $x(nT + \tau)$, which is modulated using an I/Q modulator or polar modulator 605 to form an RF signal 607. Prepending and appending of zero-valued symbols for ramp control is accomplished by inputting values to a shift register 608 through an input selector or switch 609, connected to either a source of information symbols 611 or to a source of zero values 613. A sample clock 615 is input directly to the pulse-shaping filter, and is input also to a τ counter 617 and a divide-by- T counter 619. The τ counter produces a count 621 that is input to the pulse-shaping filter. The divide-by- T counter produces from the sample clock a symbol clock 623 that is input to the shift register and applied to clock the individual stages of the shift register.

In operation, upon receipt of the first information-bearing symbol a_0 , the initial state ($n = 0$) of the shift register is $a_{n-1} = a_{n-2} = \dots = a_{n-L} = 0$. As additional symbols are received, they are shifted into the shift register. With each tick of the sample clock, the counter or index τ is updated, modulo T ; τ therefore cycles through the sequence $0, 1, \dots, T-1, 0, 1, \dots, T-1, \dots$. After the last information symbol enters the shift register, the input selector switches to accept zeros during the next L ticks of the symbol clock, until the shift register state is $a_n = \dots = a_{n-L+1} = 0$ and $a_{n-L} = a_{N-1}$, where N is the number of symbols in a burst. In this state, the ramp-down is complete once $\tau = T-1$ is reached.

Results of this technique for one complete burst with $N = 148$ symbols are shown in the plot of Figure 7. In this example, an EDGE pulse, illustrated in Figure 8, was used, with $T = 4$ (i.e., four samples per symbol) and $L + 1 = 5$ (i.e., a shift register of length five).

Figure 9 shows an exploded view of the rising edge of the ramp of a signal plot like that of Figure 7, annotated to show the value of the τ counter at each output sample, along with the contents of the shift register, updated as each new symbol is input. Note that the ramp up is basically complete within three symbols periods of the first information symbol entering the shift register.

Figure 10 shows the rising edge of the ramp when viewed on a logarithmic (dB) scale. Here it can be seen that the signal amplitude during the first symbol period is over 40dB down from the peak. In most systems (including those complying with the EDGE specification), such small signal components can be significantly distorted (e.g., clamped at zero) without causing measurable degradation of system performance (e.g., transient ACP). Various power amplifier control signals can therefore be abruptly switched during such low-amplitude times without performance degradation, described in greater detail hereinafter.

Figure 11 is similar to Figure 9 but shows the falling edge of the ramp, with zero-valued symbols entering the shift register after the last information symbol.

This appending of zero-valued symbols is accomplished in the example embodiment of Figure 6 when the input selector switches to the zero source, after the symbol clock at index $n = 147$ but before the next symbol clock at $n = 148$.

Figure 12 is a block diagram illustrating application of the present ramping technique in a polar modulator architecture, i.e., one having separate amplitude and phase paths. A symbol source 1201 inputs data symbols to a pulse modulator 1203, such as an EDGE QAM modulator, in accordance with a symbol clock 1205. The modulator produces an envelope signal 1207, for example an envelope signal like that of Figure 7, given by $x(nT + \tau)$. The envelope signal is processed by a rectangular-to-polar converter 1109 (such as a Cordic converter), producing magnitude and phase signals ρ and θ .

In an exemplary embodiment, the latter signals are corrected for non-linearities and are time aligned to account for path delay differences. Hence, the magnitude signal is applied to an AM/AM look-up table 1211, an output ρ' of which is delayed a controlled amount by a magnitude delay element 1213 to produce an output ρ'' . Similarly, the phase signal is applied to an AM/PM look-up table 1215, an output θ' of which is delayed a controlled amount by a phase delay element 1217 to produce an output θ'' . The delays of the magnitude delay element and the phase delay element are controlled to achieve proper magnitude and phase alignment at an amplification chain 1220.

The amplification chain 1220, in an exemplary embodiment, includes three cascaded stages, realized for example using FET devices. The stages are drain modulated and driven in switch mode or, for low-power operation, in "multiplicative" mode, as described more particularly in U.S. Patent Application

_____ (Attorney's Dkt. No. 110411LDM.US), filed on even date herewith and incorporated herein by reference. An RF input port 1221 of the amplification chain may be regarded as the phase port, and the drains (or power supply inputs) of the stages may be regarded together as the amplitude port 1223.

The amplitude port is driven by a driver circuit 1225, responsive to the signal p'' and to a power level input signal 1227.

The phase port is driven by a digital phase modulator 1230, preferably a digital phase modulator having a phase-stable frequency locked loop as described in U.S. Patent 6,094,101 of the present assignee, incorporated herein by reference, in combination with a VCO 1231. The digital phase modulator 1230 is isolated from the amplification chain 1220 using a variable gain amplifier (VGA) or a variable attenuator that is responsive to another power level input signal. Alternatively, the digital phase modulator may be isolated from the power amplifier using a buffer amplifier. These alternative are represented in Figure 12 by a variable gain amplifier 1233 that may have a gain that is zero (in the case of the buffer amplifier), negative (in the case of an attenuator) or positive.

A timing control block 1240 provides timing signals to the symbol source and to the driver circuit, as well as to the buffer amplifier, if present.

The transmitter of Figure 12 is mainly digital, the digital and analog (right-ports being separated by a dashed line.

The same principles described thus far, particularly with respect to ramping of the EDGE modulator, may be readily extended to embrace other modulation types, such as IS-136, also known as North American Digital Cellular or D-AMPS. The particulars of D-AMPS, however, require certain modifications to the foregoing approach.

In particular, the pulse shape used in D-AMPS, shown in Figure 13, is theoretically of infinite duration (unlike the EDGE pulse, which has a duration of 5 symbol periods). Of course, in practice, this infinite-duration pulse is truncated, the choice of the truncation interval (i.e., interval outside of which the pulse is truncated) determining the spectral characteristics (including ACP and transient ACP) of the output signal. Using the foregoing method of ramping, to obtain low side lobes, a truncation interval in the range of 8-16 symbols periods would be

required, corresponding to a ramp-up time in the range of 4-8 symbol periods and a ramp-down time in the range of 4-8 symbols periods. Unfortunately, such prolonged ramp times exceed the 3 symbol period duration specified in the D-AMPS standard. Therefore, in order to use the foregoing method for D-AMPS, or for multiple QAM modulations including EDGE, D-AMPS, etc., a mechanism of ramp acceleration is required whereby the prolonged ramp times of D-AMPS may be shortened to satisfy the specified ramp mask.

One way of achieving such ramp acceleration is illustrated in Figure 14. Here, a D-AMPS QAM modulator 1401 is provided, zero-valued symbols being prepended and appended to the information symbols belonging to a burst, as previously described in relation to EDGE. The modulator produces a digital output signal 1403 having a prescribed symbol rate. This digital output signal is applied to a discard unit 1405 controlled by a control signal 1407 from a timing generator (not shown). During ramp-up and ramp-down, a control signal is applied to the discard unit to cause it to discard selected samples (which has the equivalent effect of accelerating the time base). For example, every other sample may be discarded, resulting in 2X acceleration. During the information burst, the discard unit passes the sample stream from the modulator unchanged.

In an exemplary embodiment, the ramp-up and ramp-down times using ramp acceleration are three symbols times in duration, satisfying the specified ramp mask.

Since the signal at the original sampling rate is oversampled and is naturally bandlimited, discarding every other symbol does not create spectral side lobes or aliasing, and does not destroy signal information.

Various other means of accomplishing ramp acceleration will be apparent to those skilled in the art. For example, instead of the discard unit, an arbitrarily variable sample rate converter (sometimes referred to as an asynchronous sample rate converter) of a type known in the art may be used. Using such a sample rate

converter, the desired acceleration, instead of being limited to discrete values, may be arbitrarily chosen.

The foregoing methods are not directly applicable to PM or FM (i.e., constant envelope) signals such as the GMSK signal used in GSM, wherein zero-valued symbols do not result in a zero level output signal. However, in the case of the GMSK signal, its ideal spectrum is practically identical to that of the EDGE signal, suggesting that the same ramp shape used for EDGE could also be used for GMSK. In one particular embodiment, the first half of the EDGE pulse, $p(0)$, $p(1)$, ..., $p(2.5T)$, is used as the GMSK ramp shape for ramp up, and the rest of the EDGE pulse, $p(2.5T)$, $p(2.5T + 1)$, ..., $p(4T + T - 1)$, is used as the GMSK ramp shape for ramp down. The EDGE pulse has the characteristic that the squared magnitude of its Fourier transform is approximately proportional to the power spectrum of the GMSK communications signal.

Figure 15 illustrates application of the foregoing ramping technique for GMSK in a polar architecture having separate amplitude and phase paths. A phase path includes a GMSK PAM modulator 1501 and a frequency modulator 1503, the combination of which generates the final GMSK signal 1405. (The PAM modulator has a pulse shaping filter with an impulse response $g(t)$ tailored for GMSK.) The PAM modulator receives bits from a bit source (not shown). The bits are used by the PAM modulator and the frequency modulator to generate the GMSK signal 1505, which is applied to a phase port of a non-linear power amplifier (PA) 1510. An amplitude path includes a "hard-coded" ramp generator 1511 that uses values from the EDGE pulse $p(t)$ as previously described to generate a ramp signal 1512 that is applied to an amplitude port of the PA 1510. A timing controller 1513 receives a Start Burst signal 1515 and generates timing signals for the ramp generator and for the PAM modulator. In particular, the ramp generator and the PAM modulator are activated such that by the time an information bearing signal is applied to the phase port of the non-linear PA, the RF output signal has been fully

ramped up.

By using a non-linear PA, performance variations between production units are predictably small, with the result that the kind of unit-by-unit ramping calibration necessitated in the prior art may be eliminated, an important advantage.

Figure 16 illustrates application of the foregoing ramping technique for GMSK in a conventional I/Q architecture having a single signal path combining amplitude and phase information. In this embodiment, the PAM/FM combination of the embodiment of Figure 15 are replaced by a GMSK complex envelope generator 1601, a multiplier 1602 and an I/Q modulator 1603. A timing controller 1613 receives a Start Burst signal 1615 and generates timing signals for the ramp generator and for the GMSK complex envelope generator. In particular, the ramp generator and the GMSK complex signal generator are activated such that by the time an information bearing signal is applied to the multiplier 1602, the output signal of the ramp generator has completed a ramp-up portion.

The output $r(t)$ of the ramp generator of the foregoing embodiments is shown in Figure 17. The start of a burst corresponds to time $t = 0$, at which time ramping up begins. Ramping up is complete at time $t = 2.5T$, whereupon a "ramped-up" state begins during which information bits are transmitted. At the end of the ramped-up state, a "ramp-down" signal is generated, at a time designated as $t = u$. The ramp-down state continues until time $t = u + 2.5T$. The output $r(t)$ may therefore be expressed as:

$$r(t) = \begin{cases} p(t), & 0 \leq t \leq 2.5T \\ p(2.5T), & 2.5T \leq t \leq u \\ p(2.5T + t - u), & u \leq t \leq u + 2.5T \end{cases}$$

The duration of the ramped-up state may be defined in a digital logic implementation using a programmable counter, as is apparent to those skilled in the art of digital logic design. Upon expiration of the counter, the ramp-down sig-

nal is enabled. Similarly, counters may be used in a simple state machine to generate the indices t and u to be used in looking up values of $p(t)$ used to define $r(t)$. Other means providing equivalent signals $r(t)$ may be used as well.

Instead of storing $p(t)$ values directly on chip, a savings in area may be obtained by instead storing the N^{th} -order differences of the sequence of values. To "recall" the original sequence of values, their N^{th} -order differences are recalled and processed using an N^{th} -order accumulator, the output of which is the sequence of original values.

Ramping for GMSK signals when performed in the foregoing manner is "temporally compact;" i.e., ramp-up and ramp-down occur as quickly as possible consistent with spectral requirements.

The description thus far has described advantageous ramping techniques for varying-envelope signals such as EDGE and D-AMPS and constant-envelope signals such as GMSK. The present invention, in another aspect thereof, enables the generation of high-quality signals with good transient spectrum characteristics in which the modulation may switch (between GMSK and EDGE, for example) from slot to slot. This manner of operation is most readily achieved using polar modulation, enabling true multi-mode operation where mode switching is done on-the-fly, in real time.

Figure 18 shows a polar modulator architecture like that of Figure 12, modified for multi-mode operation. In particular, in addition to the EDGE QAM modulator of Figure 12, a D-AMPS QAM modulator 1802 and a GMSK PAM modulator 1804 are also provided, each receiving symbols from the symbol source 1801 in accordance with the sample clock 1805. A GMSK ramp generator 1710 like that of Figure 15 and Figure 16 is also provided.

Moreover, three switches are provided, controlled by the timing generator. One switch SW1 is provided at the input of the R/P converter and selects between outputs of the EDGE QAM modulator (EDGE mode) and the D-AMPS QAM

modulator (D-AMPS mode). Another switch SW2 is provided at the input of the AM/AM LUT and selects between an output of the R/P converter (non-GMSK mode, i.e., EDGE or D-AMPS) and an output of the GMSK ramp generator (GMSK mode). Another switch SW3 is provided at the input of the AM/PM LUT and selects between an output of the R/P converter (non-GMSK mode, i.e., EDGE or D-AMPS) and an output of the GMSK PAM modulator (GMSK mode).

The transmitter of Figure 18, like that of Figure 12, is mainly digital, the digital and analog portions being separated by a dashed line. Preferably, the digital portion is realized in the form of a single integrated circuit, for example a CMOS integrated circuit.

The characteristics of the ramping profile achieved in accordance with the present invention allow various power amplifier control signals to be abruptly switched during such low-amplitude times without performance degradation. An example of the interaction between ramping and overall control of a non-linear power amplifier in a polar modulation architecture will be described with reference to Figure 18.

Signals PB, P1 and Pout are used to power on and power off the buffer amplifier 1833, the first and second power amplifier stages 1820a and 1820b, and the driver circuit 1825, respectively. The timing of these signals relative to the rising edge ramp and falling edge ramp is important to control, in order to obtain good transient spectrum performance (little or no glitching caused by poorly-timed turn-on or turn-off effects). As previously described, the desired ramping amplitude characteristics may be obtained from the amplitude of a modulator's output (e.g., a QAM modulator as in EDGE) or from a ramp generator (e.g., as in GMSK). Additional timing logic is provided to generate PB, P1 and Pout as required. The implementation of such logic will be clear to those skilled in the art from the timing diagram of Figure 19, showing the desired relationship between these signals and others previously described. Whereas Figure 19 illustrates the

example of GMSK, similar relationships hold between the signals PB, P1 and Pout and the timing signals of the EDGE example (e.g., the signal or counter used to control the input selector).

Referring now to Figure 19, it may be seen that amplifiers turn on sequentially and turn off in the reverse sequence, according to their order (Figure 18) between the frequency modulator and the RF output. To achieve the highest quality signal, the switching points for PB, P1 and Pout should be selected to correspond to low amplitude times in $r(t)$, so that the associated switching transient is small. Optionally, the wasting of power may be avoided by minimizing the "on" time of each of the signals PB, P1 and Pout. This objective may be achieved, as illustrated in Figure 19, by not switching PB, P1 and Pout on until $r(t)$ is already non-zero on the ramp up, and by switching the same signals off before $r(t)$ has reached zero on the ramp down.

Beyond the general timing relationships illustrated in Figure 19, in any particular implementation, more exact timing relationships may be adjusted empirically to optimize transient spectral performance and temporal compactness. This process may be facilitated using "soft" or programmable timing logic, and need be done only once for a given implementation (not re-done for every unit during manufacture).

Thus there has been described a polar modulator architecture, amenable to a high level of integration, that enables ramping of both QAM (e.g., EDGE, D-AMPS) and non-QAM (e.g., GMSK) signals, and enabling glitch-free on-the-fly switching between different modulations (e.g., EDGE and GMSK). No unit-by-unit calibration is required, allowing ramp shapes to be fixed at design time. Timing control signals can also be fixed at design time, since they relate mainly to digital events or conditions. The particular ramping methods described produce narrow rising and falling edge ramps and very low transients (i.e., very good tran-

sient spectrum characteristics).

It will be appreciated by those of ordinary skill in the art that the invention can be embodied in other specific forms without departing from the spirit or essential character thereof. The presently disclosed embodiments are therefore considered in all respects to be illustrative and not restrictive. The scope of the invention is indicated by the appended claims rather than the foregoing description, and all changes which come within the meaning and range of equivalents thereof are intended to be embraced therein.

FIG. 1
FIG. 2
FIG. 3
FIG. 4
FIG. 5
FIG. 6
FIG. 7
FIG. 8
FIG. 9
FIG. 10
FIG. 11
FIG. 12
FIG. 13
FIG. 14
FIG. 15
FIG. 16
FIG. 17
FIG. 18
FIG. 19
FIG. 20
FIG. 21
FIG. 22
FIG. 23
FIG. 24
FIG. 25
FIG. 26
FIG. 27
FIG. 28
FIG. 29
FIG. 30
FIG. 31
FIG. 32
FIG. 33
FIG. 34
FIG. 35
FIG. 36
FIG. 37
FIG. 38
FIG. 39
FIG. 40
FIG. 41
FIG. 42
FIG. 43
FIG. 44
FIG. 45
FIG. 46
FIG. 47
FIG. 48
FIG. 49
FIG. 50
FIG. 51
FIG. 52
FIG. 53
FIG. 54
FIG. 55
FIG. 56
FIG. 57
FIG. 58
FIG. 59
FIG. 60
FIG. 61
FIG. 62
FIG. 63
FIG. 64
FIG. 65
FIG. 66
FIG. 67
FIG. 68
FIG. 69
FIG. 70
FIG. 71
FIG. 72
FIG. 73
FIG. 74
FIG. 75
FIG. 76
FIG. 77
FIG. 78
FIG. 79
FIG. 80
FIG. 81
FIG. 82
FIG. 83
FIG. 84
FIG. 85
FIG. 86
FIG. 87
FIG. 88
FIG. 89
FIG. 90
FIG. 91
FIG. 92
FIG. 93
FIG. 94
FIG. 95
FIG. 96
FIG. 97
FIG. 98
FIG. 99
FIG. 100
FIG. 101
FIG. 102
FIG. 103
FIG. 104
FIG. 105
FIG. 106
FIG. 107
FIG. 108
FIG. 109
FIG. 110
FIG. 111
FIG. 112
FIG. 113
FIG. 114
FIG. 115
FIG. 116
FIG. 117
FIG. 118
FIG. 119
FIG. 120
FIG. 121
FIG. 122
FIG. 123
FIG. 124
FIG. 125
FIG. 126
FIG. 127
FIG. 128
FIG. 129
FIG. 130
FIG. 131
FIG. 132
FIG. 133
FIG. 134
FIG. 135
FIG. 136
FIG. 137
FIG. 138
FIG. 139
FIG. 140
FIG. 141
FIG. 142
FIG. 143
FIG. 144
FIG. 145
FIG. 146
FIG. 147
FIG. 148
FIG. 149
FIG. 150
FIG. 151
FIG. 152
FIG. 153
FIG. 154
FIG. 155
FIG. 156
FIG. 157
FIG. 158
FIG. 159
FIG. 160
FIG. 161
FIG. 162
FIG. 163
FIG. 164
FIG. 165
FIG. 166
FIG. 167
FIG. 168
FIG. 169
FIG. 170
FIG. 171
FIG. 172
FIG. 173
FIG. 174
FIG. 175
FIG. 176
FIG. 177
FIG. 178
FIG. 179
FIG. 180
FIG. 181
FIG. 182
FIG. 183
FIG. 184
FIG. 185
FIG. 186
FIG. 187
FIG. 188
FIG. 189
FIG. 190
FIG. 191
FIG. 192
FIG. 193
FIG. 194
FIG. 195
FIG. 196
FIG. 197
FIG. 198
FIG. 199
FIG. 200
FIG. 201
FIG. 202
FIG. 203
FIG. 204
FIG. 205
FIG. 206
FIG. 207
FIG. 208
FIG. 209
FIG. 210
FIG. 211
FIG. 212
FIG. 213
FIG. 214
FIG. 215
FIG. 216
FIG. 217
FIG. 218
FIG. 219
FIG. 220
FIG. 221
FIG. 222
FIG. 223
FIG. 224
FIG. 225
FIG. 226
FIG. 227
FIG. 228
FIG. 229
FIG. 230
FIG. 231
FIG. 232
FIG. 233
FIG. 234
FIG. 235
FIG. 236
FIG. 237
FIG. 238
FIG. 239
FIG. 240
FIG. 241
FIG. 242
FIG. 243
FIG. 244
FIG. 245
FIG. 246
FIG. 247
FIG. 248
FIG. 249
FIG. 250
FIG. 251
FIG. 252
FIG. 253
FIG. 254
FIG. 255
FIG. 256
FIG. 257
FIG. 258
FIG. 259
FIG. 260
FIG. 261
FIG. 262
FIG. 263
FIG. 264
FIG. 265
FIG. 266
FIG. 267
FIG. 268
FIG. 269
FIG. 270
FIG. 271
FIG. 272
FIG. 273
FIG. 274
FIG. 275
FIG. 276
FIG. 277
FIG. 278
FIG. 279
FIG. 280
FIG. 281
FIG. 282
FIG. 283
FIG. 284
FIG. 285
FIG. 286
FIG. 287
FIG. 288
FIG. 289
FIG. 290
FIG. 291
FIG. 292
FIG. 293
FIG. 294
FIG. 295
FIG. 296
FIG. 297
FIG. 298
FIG. 299
FIG. 300
FIG. 301
FIG. 302
FIG. 303
FIG. 304
FIG. 305
FIG. 306
FIG. 307
FIG. 308
FIG. 309
FIG. 310
FIG. 311
FIG. 312
FIG. 313
FIG. 314
FIG. 315
FIG. 316
FIG. 317
FIG. 318
FIG. 319
FIG. 320
FIG. 321
FIG. 322
FIG. 323
FIG. 324
FIG. 325
FIG. 326
FIG. 327
FIG. 328
FIG. 329
FIG. 330
FIG. 331
FIG. 332
FIG. 333
FIG. 334
FIG. 335
FIG. 336
FIG. 337
FIG. 338
FIG. 339
FIG. 340
FIG. 341
FIG. 342
FIG. 343
FIG. 344
FIG. 345
FIG. 346
FIG. 347
FIG. 348
FIG. 349
FIG. 350
FIG. 351
FIG. 352
FIG. 353
FIG. 354
FIG. 355
FIG. 356
FIG. 357
FIG. 358
FIG. 359
FIG. 360
FIG. 361
FIG. 362
FIG. 363
FIG. 364
FIG. 365
FIG. 366
FIG. 367
FIG. 368
FIG. 369
FIG. 370
FIG. 371
FIG. 372
FIG. 373
FIG. 374
FIG. 375
FIG. 376
FIG. 377
FIG. 378
FIG. 379
FIG. 380
FIG. 381
FIG. 382
FIG. 383
FIG. 384
FIG. 385
FIG. 386
FIG. 387
FIG. 388
FIG. 389
FIG. 390
FIG. 391
FIG. 392
FIG. 393
FIG. 394
FIG. 395
FIG. 396
FIG. 397
FIG. 398
FIG. 399
FIG. 400
FIG. 401
FIG. 402
FIG. 403
FIG. 404
FIG. 405
FIG. 406
FIG. 407
FIG. 408
FIG. 409
FIG. 410
FIG. 411
FIG. 412
FIG. 413
FIG. 414
FIG. 415
FIG. 416
FIG. 417
FIG. 418
FIG. 419
FIG. 420
FIG. 421
FIG. 422
FIG. 423
FIG. 424
FIG. 425
FIG. 426
FIG. 427
FIG. 428
FIG. 429
FIG. 430
FIG. 431
FIG. 432
FIG. 433
FIG. 434
FIG. 435
FIG. 436
FIG. 437
FIG. 438
FIG. 439
FIG. 440
FIG. 441
FIG. 442
FIG. 443
FIG. 444
FIG. 445
FIG. 446
FIG. 447
FIG. 448
FIG. 449
FIG. 450
FIG. 451
FIG. 452
FIG. 453
FIG. 454
FIG. 455
FIG. 456
FIG. 457
FIG. 458
FIG. 459
FIG. 460
FIG. 461
FIG. 462
FIG. 463
FIG. 464
FIG. 465
FIG. 466
FIG. 467
FIG. 468
FIG. 469
FIG. 470
FIG. 471
FIG. 472
FIG. 473
FIG. 474
FIG. 475
FIG. 476
FIG. 477
FIG. 478
FIG. 479
FIG. 480
FIG. 481
FIG. 482
FIG. 483
FIG. 484
FIG. 485
FIG. 486
FIG. 487
FIG. 488
FIG. 489
FIG. 490
FIG. 491
FIG. 492
FIG. 493
FIG. 494
FIG. 495
FIG. 496
FIG. 497
FIG. 498
FIG. 499
FIG. 500
FIG. 501
FIG. 502
FIG. 503
FIG. 504
FIG. 505
FIG. 506
FIG. 507
FIG. 508
FIG. 509
FIG. 510
FIG. 511
FIG. 512
FIG. 513
FIG. 514
FIG. 515
FIG. 516
FIG. 517
FIG. 518
FIG. 519
FIG. 520
FIG. 521
FIG. 522
FIG. 523
FIG. 524
FIG. 525
FIG. 526
FIG. 527
FIG. 528
FIG. 529
FIG. 530
FIG. 531
FIG. 532
FIG. 533
FIG. 534
FIG. 535
FIG. 536
FIG. 537
FIG. 538
FIG. 539
FIG. 540
FIG. 541
FIG. 542
FIG. 543
FIG. 544
FIG. 545
FIG. 546
FIG. 547
FIG. 548
FIG. 549
FIG. 550
FIG. 551
FIG. 552
FIG. 553
FIG. 554
FIG. 555
FIG. 556
FIG. 557
FIG. 558
FIG. 559
FIG. 560
FIG. 561
FIG. 562
FIG. 563
FIG. 564
FIG. 565
FIG. 566
FIG. 567
FIG. 568
FIG. 569
FIG. 570
FIG. 571
FIG. 572
FIG. 573
FIG. 574
FIG. 575
FIG. 576
FIG. 577
FIG. 578
FIG. 579
FIG. 580
FIG. 581
FIG. 582
FIG. 583
FIG. 584
FIG. 585
FIG. 586
FIG. 587
FIG. 588
FIG. 589
FIG. 590
FIG. 591
FIG. 592
FIG. 593
FIG. 594
FIG. 595
FIG. 596
FIG. 597
FIG. 598
FIG. 599
FIG. 600
FIG. 601
FIG. 602
FIG. 603
FIG. 604
FIG. 605
FIG. 606
FIG. 607
FIG. 608
FIG. 609
FIG. 610
FIG. 611
FIG. 612
FIG. 613
FIG. 614
FIG. 615
FIG. 616
FIG. 617
FIG. 618
FIG. 619
FIG. 620
FIG. 621
FIG. 622
FIG. 623
FIG. 624
FIG. 625
FIG. 626
FIG. 627
FIG. 628
FIG. 629
FIG. 630
FIG. 631
FIG. 632
FIG. 633
FIG. 634
FIG. 635
FIG. 636
FIG. 637
FIG. 638
FIG. 639
FIG. 640
FIG. 641
FIG. 642
FIG. 643
FIG. 644
FIG. 645
FIG. 646
FIG. 647
FIG. 648
FIG. 649
FIG. 650
FIG. 651
FIG. 652
FIG. 653
FIG. 654
FIG. 655
FIG. 656
FIG. 657
FIG. 658
FIG. 659
FIG. 660
FIG. 661
FIG. 662
FIG. 663
FIG. 664
FIG. 665
FIG. 666
FIG. 667
FIG. 668
FIG. 669
FIG. 670
FIG. 671
FIG. 672
FIG. 673
FIG. 674
FIG. 675
FIG. 676
FIG. 677
FIG. 678
FIG. 679
FIG. 680
FIG. 681
FIG. 682
FIG. 683
FIG. 684
FIG. 685
FIG. 686
FIG. 687
FIG. 688
FIG. 689
FIG. 690
FIG. 691
FIG. 692
FIG. 693
FIG. 694
FIG. 695
FIG. 696
FIG. 697
FIG. 698
FIG. 699
FIG. 700
FIG. 701
FIG. 702
FIG. 703
FIG. 704
FIG. 705
FIG. 706
FIG. 707
FIG. 708
FIG. 709
FIG. 710
FIG. 711
FIG. 712
FIG. 713
FIG. 714
FIG. 715
FIG. 716
FIG. 717
FIG. 718
FIG. 719
FIG. 720
FIG. 721
FIG. 722
FIG. 723
FIG. 724
FIG. 725
FIG. 726
FIG. 727
FIG. 728
FIG. 729
FIG. 730
FIG. 731
FIG. 732
FIG. 733
FIG. 734
FIG. 735
FIG. 736
FIG. 737
FIG. 738
FIG. 739
FIG. 740
FIG. 741
FIG. 742
FIG. 743
FIG. 744
FIG. 745
FIG. 746
FIG. 747
FIG. 748
FIG. 749
FIG. 750
FIG. 751
FIG. 752
FIG. 753
FIG. 754
FIG. 755
FIG. 756
FIG. 757
FIG. 758
FIG. 759
FIG. 760
FIG. 761
FIG. 762
FIG. 763
FIG. 764
FIG. 765
FIG. 766
FIG. 767
FIG. 768
FIG. 769
FIG. 770
FIG. 771
FIG. 772
FIG. 773
FIG. 774
FIG. 775
FIG. 776
FIG. 777
FIG. 778
FIG. 779
FIG. 780
FIG. 781
FIG. 782
FIG. 783
FIG. 784
FIG. 785
FIG. 786
FIG. 787
FIG. 788
FIG. 789
FIG. 790
FIG. 791
FIG. 792
FIG. 793
FIG. 794
FIG. 795
FIG. 796
FIG. 797
FIG. 798
FIG. 799
FIG. 800
FIG. 801
FIG. 802
FIG. 803
FIG. 804
FIG. 805
FIG. 806
FIG. 807
FIG. 808
FIG. 809
FIG. 810
FIG. 811
FIG. 812
FIG. 813
FIG. 814
FIG. 815
FIG. 816
FIG. 817
FIG. 818
FIG. 819
FIG. 820
FIG. 821
FIG. 822
FIG. 823
FIG. 824
FIG. 825
FIG. 826
FIG. 827
FIG. 828
FIG. 829
FIG. 830
FIG. 831
FIG. 832
FIG. 833
FIG. 834
FIG. 835
FIG. 836
FIG. 837
FIG. 838
FIG. 839
FIG. 840
FIG. 841
FIG. 842
FIG. 843
FIG. 844
FIG. 845
FIG. 846
FIG. 847
FIG. 848
FIG. 849
FIG. 850
FIG. 851
FIG. 852
FIG. 853
FIG. 854
FIG. 855
FIG. 856
FIG. 857
FIG. 858
FIG. 859
FIG. 860
FIG. 861
FIG. 862
FIG. 863
FIG. 864
FIG. 865
FIG. 866
FIG. 867
FIG. 868
FIG. 869
FIG. 870
FIG. 871
FIG. 872
FIG. 873
FIG. 874
FIG. 875
FIG. 876
FIG. 877
FIG. 878
FIG. 879
FIG. 880
FIG. 881
FIG. 882
FIG. 883
FIG. 884
FIG. 885
FIG. 886
FIG. 887
FIG. 888
FIG. 889
FIG. 890
FIG. 891
FIG. 892
FIG. 893
FIG. 894
FIG. 895
FIG. 896
FIG. 897
FIG. 898
FIG. 899
FIG. 900
FIG. 901
FIG. 902
FIG. 903
FIG. 904
FIG. 905
FIG. 906
FIG. 907
FIG. 908
FIG. 909
FIG. 910
FIG. 911
FIG. 912
FIG. 913
FIG. 914
FIG. 915
FIG. 916
FIG. 917
FIG. 918
FIG. 919
FIG. 920
FIG. 921
FIG. 922
FIG. 923
FIG. 924
FIG. 925
FIG. 926
FIG. 927
FIG. 928
FIG. 929
FIG. 930
FIG. 931
FIG. 932
FIG. 933
FIG. 934
FIG. 935
FIG. 936
FIG. 937
FIG. 938
FIG. 939
FIG. 940
FIG. 941
FIG. 942
FIG. 943
FIG. 944
FIG. 945
FIG. 946
FIG. 947
FIG. 948
FIG. 949
FIG. 950
FIG. 951
FIG. 952
FIG. 953
FIG. 954
FIG. 955
FIG. 956
FIG. 957
FIG. 958
FIG. 959
FIG. 960
FIG. 961
FIG. 962
FIG. 963
FIG. 964
FIG. 965
FIG. 966
FIG. 967
FIG. 968
FIG. 969
FIG. 970
FIG. 971
FIG. 972
FIG. 973
FIG. 974
FIG. 975
FIG. 976
FIG. 977
FIG. 978
FIG. 979
FIG. 980
FIG. 981
FIG. 982
FIG. 983
FIG. 984
FIG. 985
FIG. 986
FIG. 987
FIG. 988
FIG. 989
FIG. 990
FIG. 991
FIG. 992
FIG. 993
FIG. 994
FIG. 995
FIG. 996
FIG. 997
FIG. 998
FIG. 999
FIG. 1000